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PHOTOVOLTAICS

Photovoltaic Systems for Government Agencies

MICHAEL G. THOMAS
HAROLD N. POST
ANNE VANARSDALL

REVISED FEBRUARY 1994

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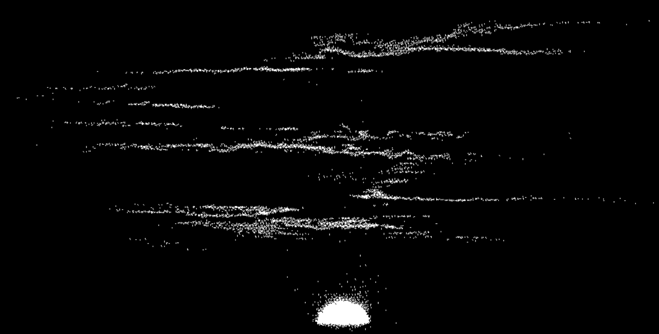

The PVDAC is a national resource for technical information about photovoltaic systems. Established in 1984 as part of the U. S. Department of Energy's National Photovoltaic Program, the PVDAC staff provides technical support and stimulates transfer of the technology by putting potential users of photovoltaic systems in touch with suppliers of systems and components. Many government agencies have gained experience with photovoltaic systems in the last few years. The PVDAC supports this "in-house expertise" and works with agencies to help them find solutions to their power demand needs. Mike Thomas and Hal Post are the contact persons for the PVDAC. The telephone number is (505) 844-1548 or (505) 844-2154. Call for information about the systems in this document, possible applications in your area, local solar resource data, or industry contacts.

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All around the country photovoltaic systems are providing reliable power for lighting, communications, remote site electrification, remote monitoring, warning signs, water pumping, restroom facilities, vehicle battery charging, cathodic protection and facility power. It is no wonder that photovoltaic power supplies are now the standard for many agencies. The U.S. Coast Guard uses photovoltaic power exclusively for its remote navigation aids. The National Park Service (NPS) is rapidly increasing the number of installed photovoltaic systems at its remote facilities because they are compatible with the NPS's objective of sustainable design. The list goes on! The demand for photovoltaic modules increases each year. In 1993, approximately 20 megawatts of U.S. supplied collectors were installed in stand-alone photovoltaic systems like the ones described in this publication.

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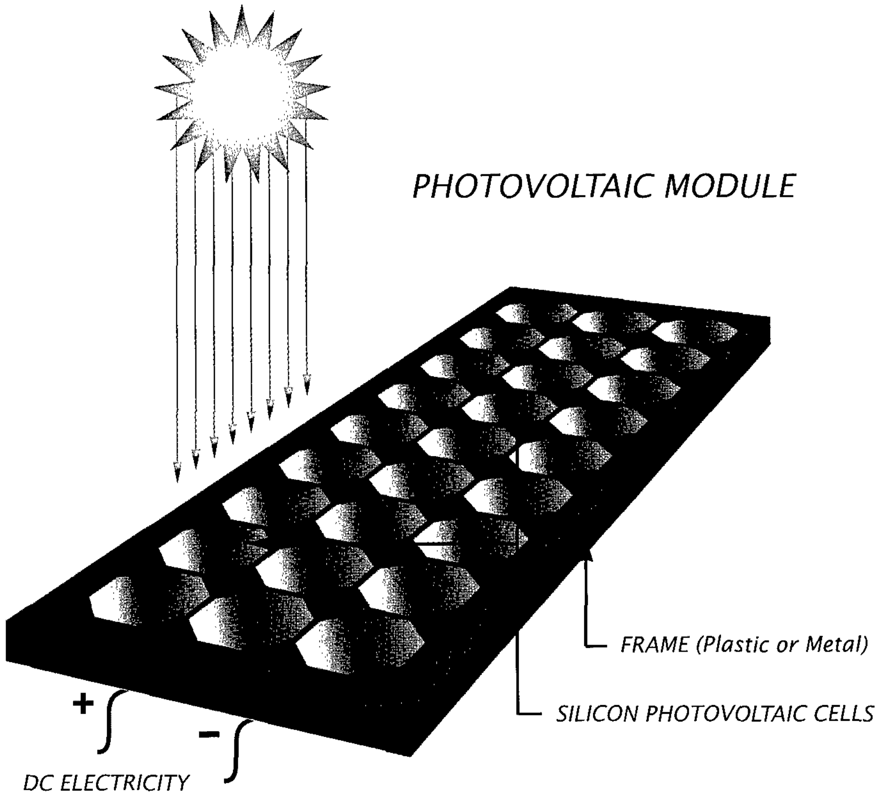
Why are so many local, state, tribal, and federal agencies using photovoltaic systems to meet their energy needs? For the best reason—they are the least expensive way to get reliable power for many applications. Consider the advantages that photovoltaic systems have over competing power options:

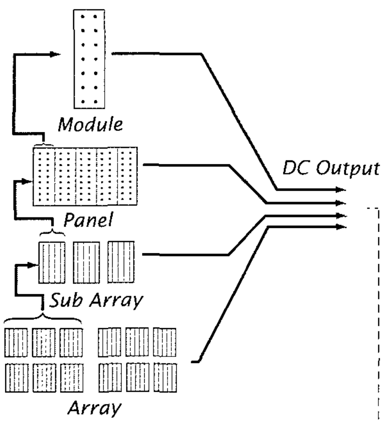
- They have no moving parts and produce power silently
- They are non-polluting with no detectable emissions or odors
- They are inherently stand-alone systems that reliably operate unattended for long periods
- They require no connection to an existing power source or fuel supply
- They may be combined with other power sources to increase system reliability (hybrid systems)
- They can withstand severe weather conditions including snow and ice
- They consume no fossil fuels—their fuel is abundant and free
- They can be installed as modular building blocks—as your power demand increases, you may add more photovoltaic modules.

All around the country photovoltaic systems are providing reliable power for lighting, communications, remote site electrification, remote monitoring, warning signs, water pumping, restroom facilities, vehicle battery charging, cathodic protection and facility power. It is no wonder that photovoltaic power supplies are now the standard for many agencies. The U.S. Coast Guard uses photovoltaic power exclusively for its remote navigation aids. The National Park Service (NPS) is rapidly increasing the number of installed photovoltaic systems at its remote facilities because they are compatible with the NPS's objective of sustainable design. Municipal governments throughout California use photovoltaic power for emergency call-boxes located along their freeways. Many other state and municipal governments are now installing these emergency phones as an aid to motorists. The U.S. Geological Survey uses photovoltaic power systems at remote sites for telecommunications and for remote monitoring stations. The list goes on! The demand for photovoltaic modules increases each year. In 1993, approximately 20 megawatts of U.S. supplied collectors were installed in stand-alone photovoltaic systems like the ones described in this publication.

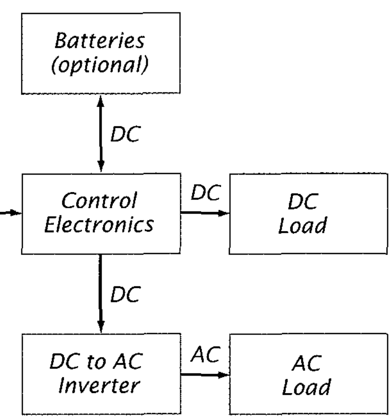


PHOTOVOLTAIC EFFECT Photovoltaic describes a technology in which radiant energy from the sun is converted to direct current (dc) electricity. Although the scientific basis of the photovoltaic effect has been known for nearly 150 years, the modern photovoltaic cell was not developed until 1954. Only four years later the first cells were providing power for U.S. spacecraft. Some of these early systems are still operating in space today and attest to the reliability and durability of the technology. Most solar cells are made of silicon semiconductor material treated with special additives. When sunlight strikes the cells, a flow of electrons is generated proportional to the intensity of the sunlight and the area of the cell. A solar cell 10 centimeters on a side will produce about 3.5 amperes in full sunlight. Each solar cell produces approximately one-half volt. Higher voltages are obtained by connecting solar cells in series. The typical photovoltaic module used for terrestrial applications contains 36 silicon solar cells, connected in series to provide enough voltage to charge a 12-volt battery. The series-connected solar cells are encapsulated and sealed, most with a tempered glass cover and a soft plastic backing sheet. The laminated module protects the electrical circuits from the environment and gives the long life that photovoltaic modules are noted for. Modules may be connected in series to obtain required system voltages or in parallel to obtain larger currents. This modularity—capability to install just the amount of power required—is an advantage for the photovoltaic system designer.

PHOTOVOLTAIC SYSTEMS Photovoltaic modules produce electricity for a connected load when the sun is shining—some electricity is even produced on cloudy days. However, for many applications the electrical energy is needed at night so storage batteries are required. In these cases, the photovoltaic system can be considered as an uninterruptible power supply with battery charging provided daily by the photovoltaic modules. In addition, all systems include wire, connectors, switches, and electrical protective components. If the load requires alternating current (ac), an inverter is used to convert the dc power to ac power. A simplified block diagram of a typical photovoltaic power system is shown below.



In 1973-1974 during the oil embargo, the U.S. Department of Energy funded the Federal Photovoltaic Utilization Program, the first large-scale program to test and demonstrate the value of photovoltaic systems for terrestrial applications. Nine federal agencies including the Departments of Agriculture, Commerce, Defense, Interior, Transportation, Health and Human Services, the Treasury, the Environmental Protection Agency, and the General Services Administration participated in this effort. Together they installed over 3,100 systems, many of which are still operating today. These systems helped to prove the reliability and competitiveness of photovoltaic power systems in practical field applications. The information and experience gained from the program, coupled with product improvements and decreases in cost, paved the way for the widespread use of photovoltaic systems today. In the last decade over 100 megawatts of U.S.-produced photovoltaic power has been installed worldwide. Most systems are at remote sites where the power demand is relatively small (<1000 watts). Photovoltaic systems are often the most economical option for this type of application. Government agencies at all levels have applications that fit this general description. If you know of similar applications we encourage you to consider photovoltaic systems.



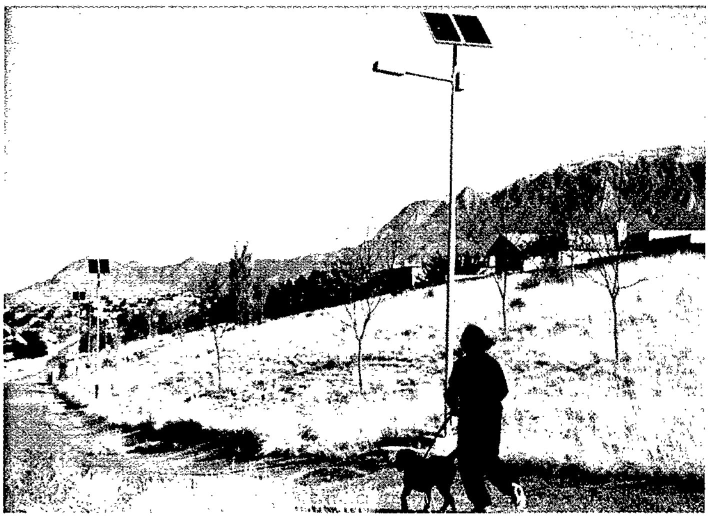
Lighting

Cost-effective photovoltaic powered lighting systems are operating throughout the world. They illuminate billboards, highway information signs, secure installations, public-use facilities, bus stops, parking lots, marinas, remote facilities, homes and vacation cabins. Recent improvements in the efficiency and reliability of dc lamps, coupled with reductions in the cost of photovoltaic modules, have significantly improved the economic competitiveness of these systems. In many cases, lighting can be powered by photovoltaic systems at a fraction of the cost of extending utility lines to remote areas. The lamps can be controlled by timers, photocells, or sensors. Pre-packaged systems containing photovoltaic modules, batteries, lamps, ballasts, and controls are available from many photovoltaic system dealers. Photovoltaic lighting systems typically operate at 12 or 24 volts dc. Most systems use fluorescent lamps because they are up to four times more efficient than incandescent lamps. However, incandescent, halogen, fluorescent, and low-pressure sodium lamps have been used with photovoltaic power. Batteries are required in photovoltaic-powered lighting systems. The energy collected during the day is stored for use during the night. A battery charge controller is included in the typical lighting system to avoid overcharging the battery or to prevent battery damage from deep discharge. Also, the batteries should be protected from temperature extremes. The photovoltaic modules may be mounted on a pole, on the ground, or on the structure to be illuminated but they must have an unobstructed view of the sun. Elevating the photovoltaic array can reduce the risk of vandalism and make it easier to avoid shading.

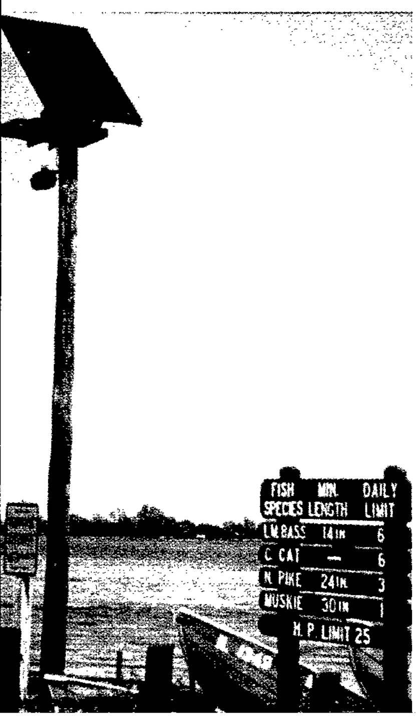
This lighted sign powered by a 400 watt photovoltaic system was installed in Brevard County Florida in 1988 by the Florida Department of Transportation. Only routine maintenance has been required. The Florida DOT continues to install photovoltaic lighting systems because of the performance and cost savings offered by these reliable signs.

This photovoltaic lighting system welcomes travelers to Grand Junction, Colorado. It has provided reliable lighting since installation in 1988. The photovoltaic modules are mounted on a short pole with the batteries located in a weather-resistant box at the foot of the pole. The wire is run underground to the fluorescent lamps.

Many cities are using photovoltaic power systems to light bus shelters. This one in Tucson, Arizona, uses a timer to operate the lights from sundown to midnight and from 5 a.m. to dawn. Many city governments are finding it easier and cheaper to install photovoltaic power than to have the utility install a transformer and grid extension for this urban application.



This photovoltaic-powered municipal lighting system includes twenty one lights along a bike/walking path in Albuquerque, New Mexico. The City Parks and Recreation Department installed the lights as the least-cost option in 1989. The lights were recently refurbished with new batteries.

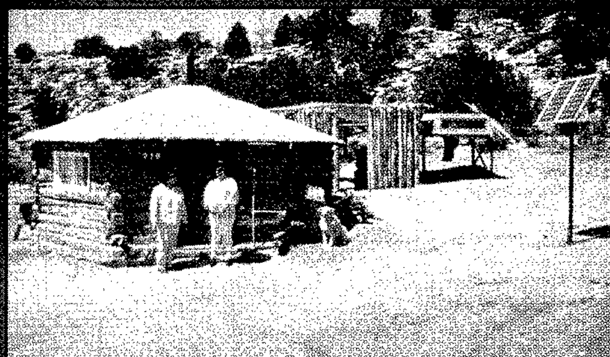


The Illinois Department of Energy and Natural Resources is using photovoltaic systems to provide lighting in state parks and wildlife areas. Fifteen systems are now operating. The only problem experienced has been some vandalism and theft. The agency is planning additional installations because of the reliable performance and cost-effectiveness of the systems.

Photovoltaic Systems Solve Problems

THE NAVAJO NATION

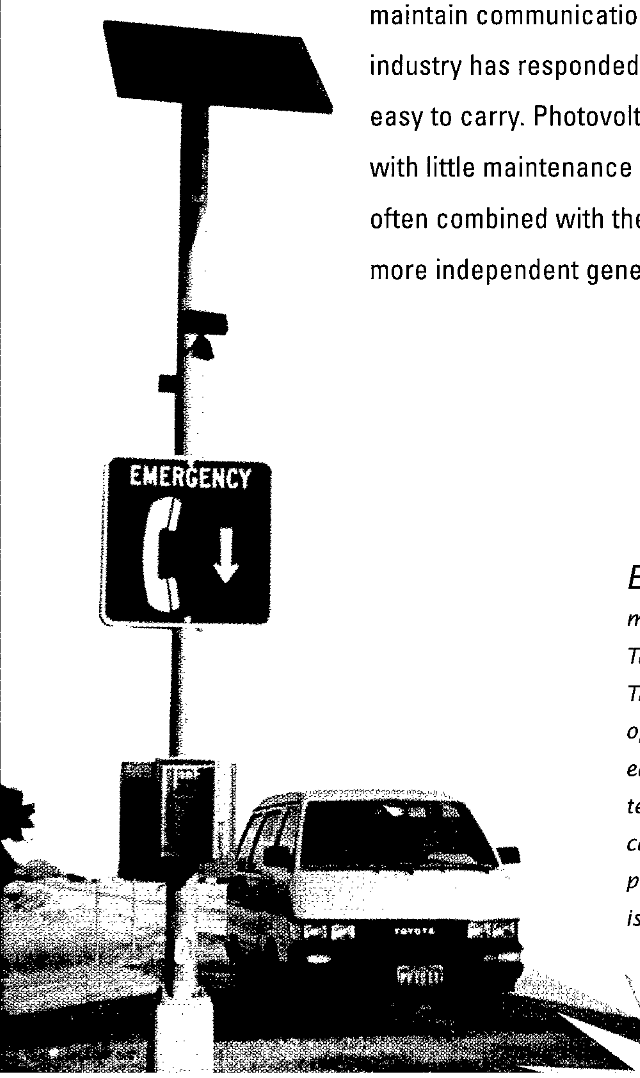
The Navajo Nation covers about 25,000 square miles in the states of Arizona, New Mexico, and Utah, an area greater in size than Connecticut, Massachusetts, Vermont, and Rhode Island combined. Photovoltaic systems have been used by the Navajo Nation since 1978 and over 1000 systems like the one shown have been installed. The Navajo Tribal Utility Authority (NTUA) is responsible for providing power to the residents, and has developed a utility distribution grid in areas where there are village/population centers. However, it is not economical for NTUA to extend a utility line to the many isolated residences.



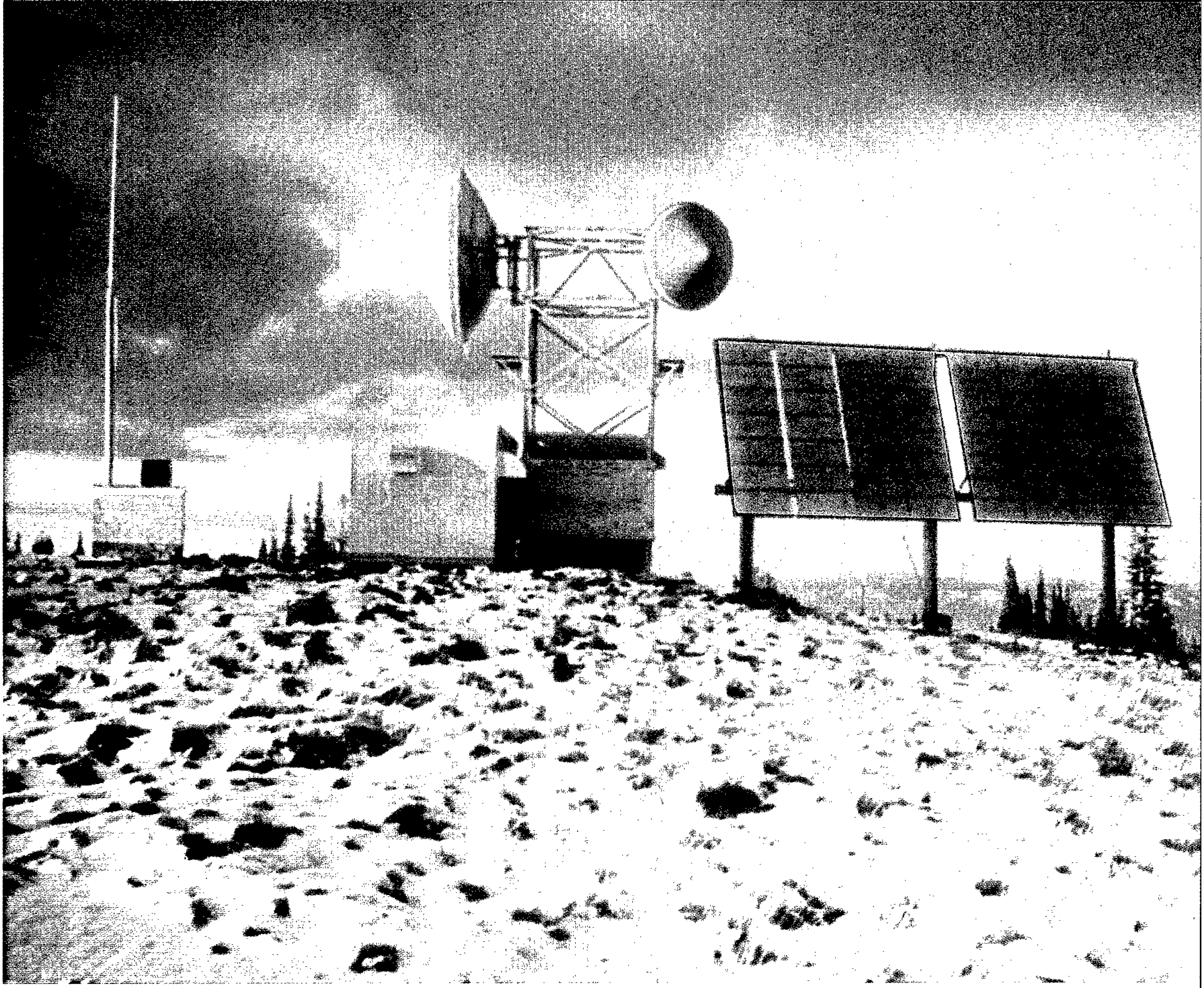
Because of the reliability and low maintenance requirements of photovoltaic systems, the NTUA is using them for electrifying these remote residences. The PVDAC is helping define requirements and develop standard hardware and designs for NTUA.

Communications

Several thousand photovoltaic systems are providing reliable power for communications systems. Examples include communication relay towers, travelers' information transmitters, cellular telephones, mobile radio systems, emergency call boxes, and military test facilities. These systems range in size from a few watts for call-box systems to several kilowatts for microwave repeater stations. Some of the loads are critical to life and require highly reliable power systems. Photovoltaic systems are ideal for communications hardware because the photovoltaic-charged battery provides a stable dc voltage and easily meets the varying current demand. Many communications systems are in remote areas with extreme weather conditions such as high winds, heavy snows, and ice. The military is using portable photovoltaic systems for charging batteries to maintain communications between forward units and headquarters. The photovoltaic industry has responded to this application with modules that are flexible, lightweight, and easy to carry. Photovoltaic power systems are a good choice because they operate reliably with little maintenance required. For larger systems at remote sites, an engine generator is often combined with the photovoltaic/battery system. These hybrid systems with two or more independent generators can achieve system availabilities near 100 percent.

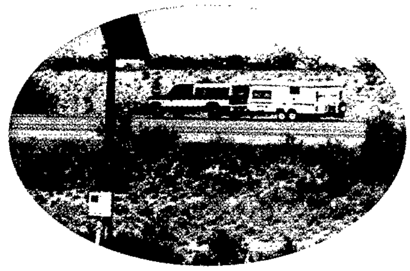


Emergency telephone call boxes powered by photovoltaic modules are commonplace in western states. This is one of 20 units between Tucson, Arizona and Nogales, Mexico. In California, the Orange County Transportation Commission has installed over 1000 units along 137 miles of its freeways. Those systems have been operating since 1987 with few equipment problems. Thousands of motorists have used these cellular telephones to report an emergency or request assistance. The call boxes can be installed and, if necessary, moved by simply pouring a concrete pedestal and bolting the packaged unit in place. Extending utility power is not a competitive option.



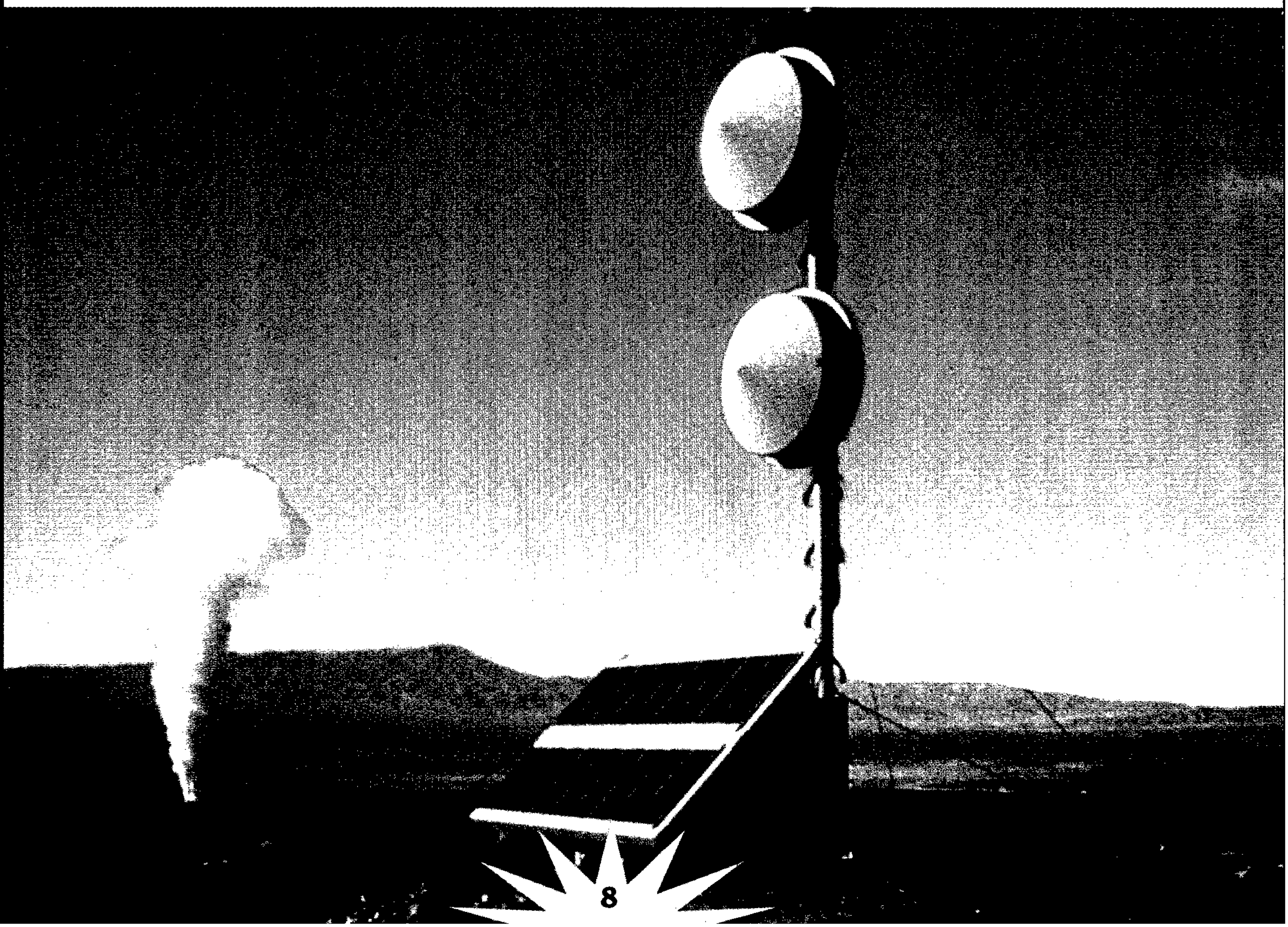
This photovoltaic-powered telephone communications relay station installed on Iron Mountain near Elk City, Idaho is typical of many systems operating throughout mountainous areas of the western United States. The system was installed in 1986. In 1990 the size of the photovoltaic power system was increased by 25% because of steady growth in the load power demand. Because of the reliability and operability of the photovoltaic systems, the U.S. Forest Service and other users are installing these larger photovoltaic systems to replace engine generators at many remote sites. The generators are relegated to a back-up role with photovoltaics sized to carry the load most of the time. This decreased dependence on engines lowers the cost of fuel transport, storage, and maintenance.

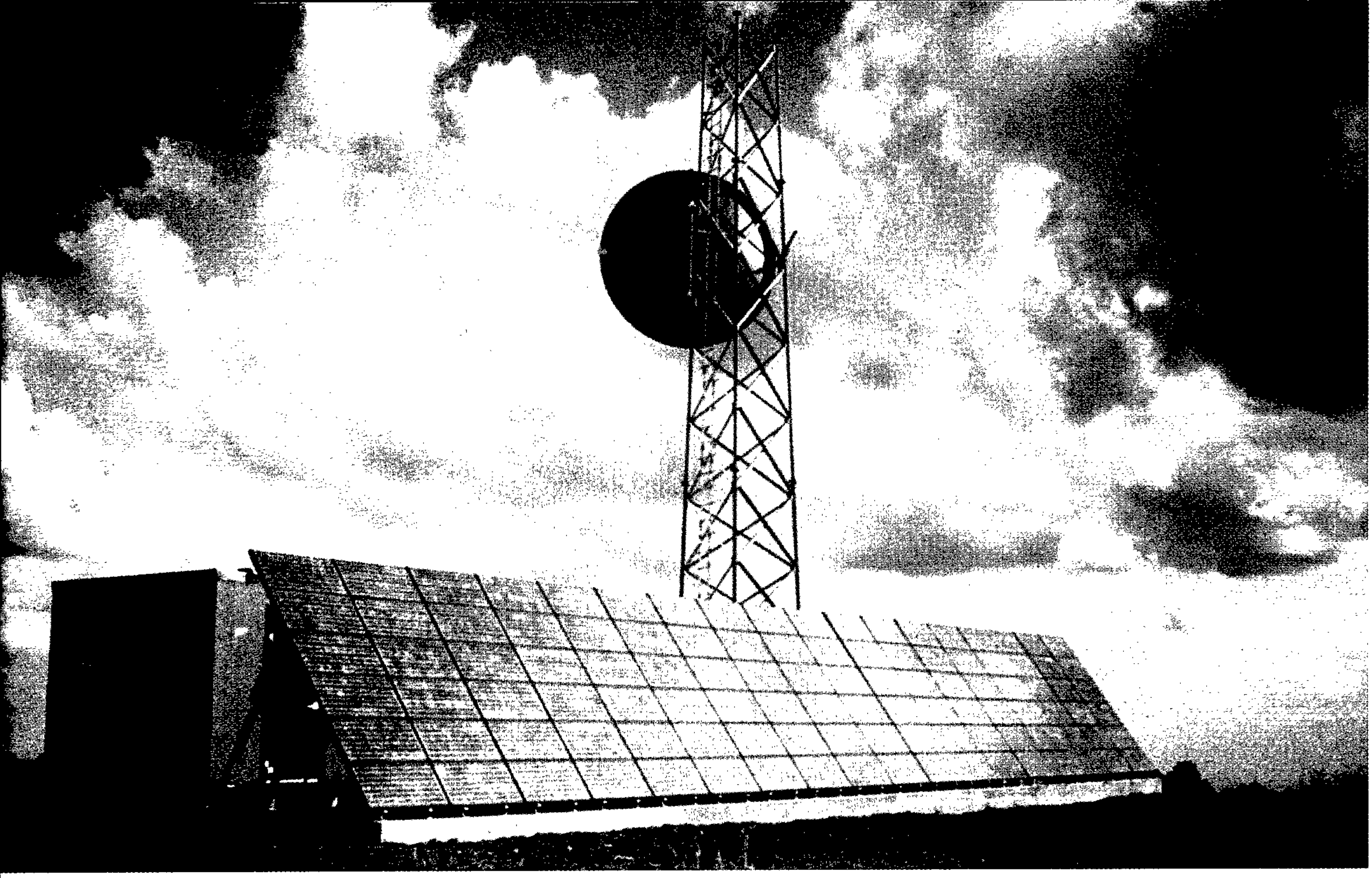
The State of New Mexico Highway Department has installed travelers' information radios powered by photovoltaic systems along major highways throughout the southern part of the state. Travelers may tune their radio to 530 kHz on the AM band and hear a recorded message with interesting facts about the surrounding area. Using a photovoltaic power system allows flexibility when siting the antenna/system for good broadcast area coverage. This system is located near Socorro, New Mexico.



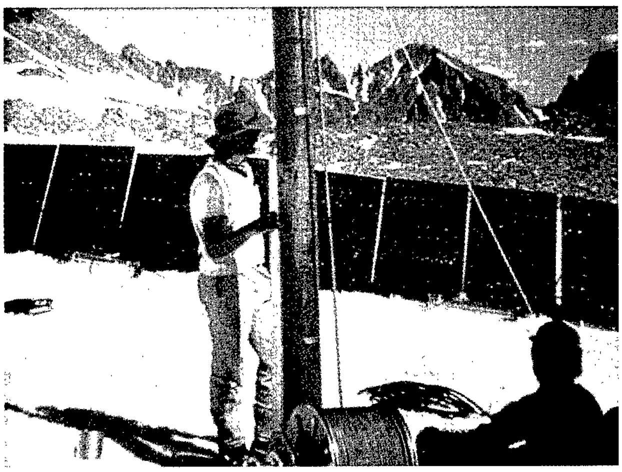
Remote Site Electrification

Photovoltaic systems are the solution of choice for many agencies that must provide long-term power at sites far from established electric service. Thousands of photovoltaic systems are being installed each year to power rural residences, visitors centers in parks, vacation cabins, village/island electrification, clinics/remote research facilities, and military test areas. The varied loads include lighting, small appliances, water pumps, and communications equipment. The load demand varies from a few watts to tens of kilowatts. As the cost of photovoltaic systems decreases, some operators are using photovoltaics to replace fueled generators and their associated problems with maintenance.

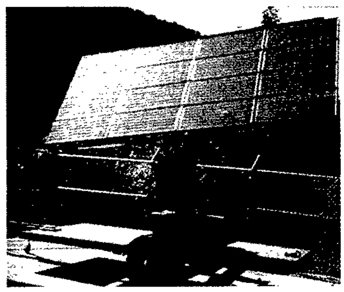




Phone service for Halls Crossing and Bullfrog Marina is provided by this telephone repeater located at Upper Horse Flats near the Glen Canyon National Recreational Area. This photovoltaic/engine hybrid system includes a propane generator and was sized such that the generator operates primarily during the winter months.



When the U.S. Geological Survey (USGS) needed power to drill a 500-ft deep ice core on the Fremont glacier in Wyoming, it used photovoltaic power to provide 2.8-kW at 120 or 240 volts dc. A helicopter was used to get the equipment to the glacier where the USGS spent one month taking ice cores.

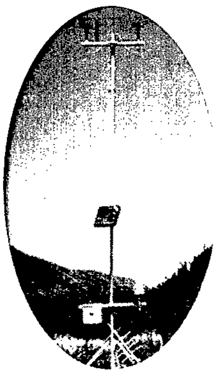


This trailer-mounted photovoltaic system is being used by the U.S. Forest Service to meet seasonal power needs. This 1.0 kW system is being used at the Las Huertas picnic site in the Cibola National Forest, New Mexico to provide power for lights, water pumping and disinfection, toilet building ventilation, and a host trailer for the caretaker.

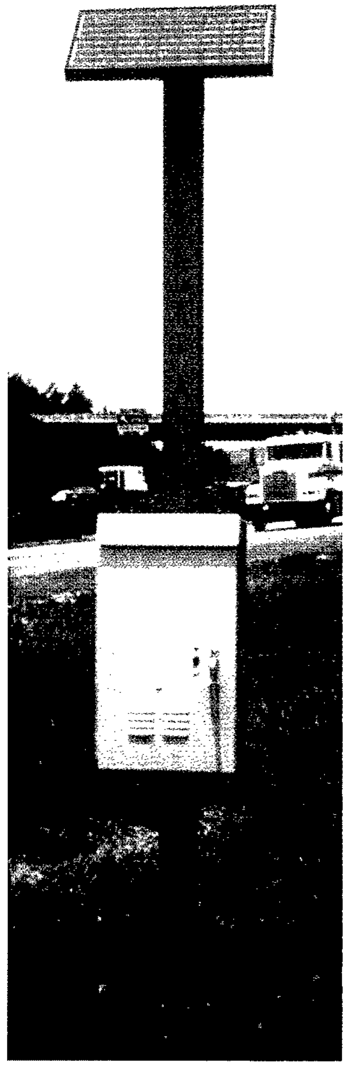
The U.S. Navy powers this radar simulator at its Fallon, Nevada test range with a photovoltaic system. This system, mounted high on a remote mountain, was clearly the most cost-effective power option for this site.

Remote Monitoring

Many government agencies require data from sensors installed at remote sites. Providing power to these sensors, dataloggers, and associated transmitters is a natural application for photovoltaic systems. Most applications require less than 200 watts and include monitors for meteorological information, highway/traffic conditions, structural conditions, seismic recording, irrigation control, and scientific research. Photovoltaic power supplies are ideal for this application because of their simplicity, reliability, and capability to operate unattended. Also, many monitoring systems operate at 12 volts dc and require only one photovoltaic module to keep the battery charged. Vandalism may be a problem in some areas, so non-glass-covered modules are sometimes used. Mounting the modules on a tall pole or in an unobtrusive manner may also help avoid damage or theft. The batteries are often located in the same weather-resistant enclosure as the data acquisition/monitoring equipment. This enclosure is sometimes camouflaged or buried for protection. Some dataloggers come with their own battery and charge regulator. The addition of a small photovoltaic module completes an inexpensive power system.

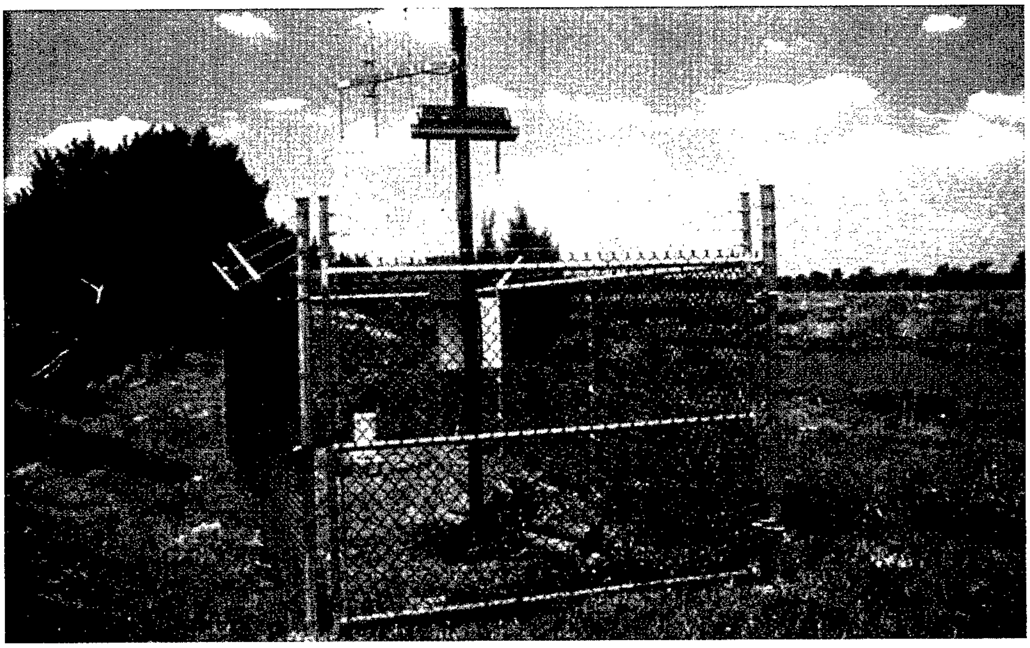


The U.S. Geological Survey maintains many photovoltaic-powered monitoring stations like the one shown on Mt. St. Helens in Washington. Weather and seismic data are transmitted via radio-frequency link to a central facility. The complete system can be set up in less than one hour and will operate unattended for years.



The North Carolina Department of Transportation is one of many states using photovoltaic powered sensors to monitor traffic on the highways. These self-contained portable systems can be moved and set up easily with no need to worry about power at the site. North Carolina has more than 200 units operating throughout the state.

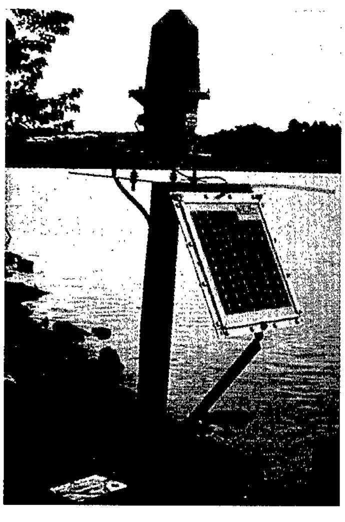
The Colorado Division of Wildlife uses a photovoltaic system to provide power to a water valve that controls flow into a fish hatchery. This system has been working without failure since it was installed in 1987.



This small photovoltaic-powered system is used to monitor the water level and quality of the St. John's river in Florida. The station has been transmitting data to the St. John's River Water Management District since 1990.

Signs and Signals

The most popular application for photovoltaic systems is for warning signs. Typical systems are for navigational beacons, audible signals such as sirens, highway warning signs, railroad signals, and aircraft warning beacons. The United States military, the Coast Guard, state highway departments, railroads, airport authorities and many others are using photovoltaic power to inform and warn the public. Even electric utility companies are using photovoltaic power for warning lights on some high-voltage distribution towers because it is less expensive than the transformer required to provide ac power from their own utility lines. Because these signals are critical to public safety, they must be operative at all times, and thus the reliability of the photovoltaic system is extremely important. The U.S. Coast Guard uses many solar-powered systems with large-capacity batteries and no charge control. These simple systems provide the ultimate in reliability. Many of these systems operate in harsh environments. For maritime applications, special modules are used that are resistant to corrosion from salt water. The Coast Guard has set its own stringent requirements based on the experience of operating nearly 14,000 systems in the past few years. In 1984, the Coast Guard began to convert all navigational buoys from primary batteries to photovoltaic-powered rechargeable batteries and is saving millions of dollars a year on the cost of batteries and the labor required to replace and recycle them.

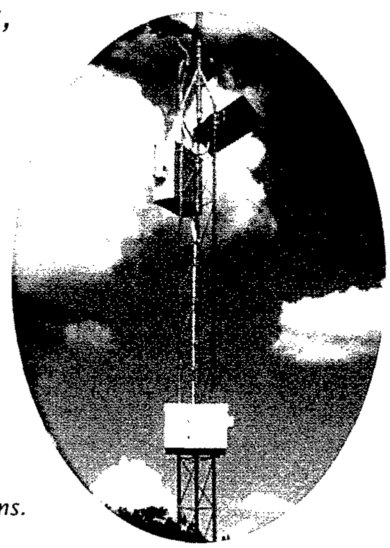


This single-module system is typical of the 14,000 sites the U.S. Coast Guard has converted from primary batteries. This module is covered to protect against vandalism.

The Anacapa lighthouse photovoltaic power system in the Channel Islands National Park, California, was expanded in 1993 by the U. S. Coast Guard. The additional power is used for a high-intensity foghorn and communications equipment.

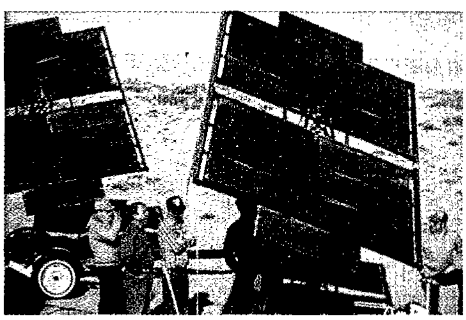
This photovoltaic-powered school crossing warning light was installed in 1993 by the Albuquerque General Services Department. Photovoltaics provided the city with a lower cost power option than tying into the nearby utility service.

West of Austin, Texas, six towers with flash flood warning sirens alert visitors along a 3-mile stretch of riverbank at Pedernales Falls State Park. The sensors and sirens are powered by photovoltaic systems and have been operating since 1983. The State of Texas Division of Parks and Wildlife has installed more systems because of the reliable performance of the original systems.



Water pumping and Control

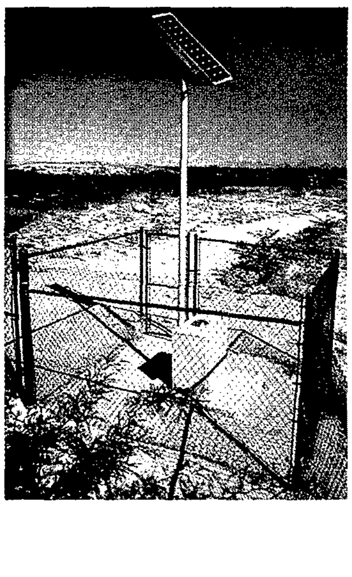
Around the world, water is pumped by a variety of methods, and no single technique is suitable for the range of existing needs. Stand-alone photovoltaic systems are increasingly being used to meet the need for intermediate-sized pumping applications—those between hand pumps and large engine-powered systems. This is the fastest growing market segment with thousands of photovoltaic-powered water pumps being installed in the United States and abroad each year. These applications include domestic use, water for campgrounds, irrigation, village water supplies, and livestock watering. The latter category, livestock watering, is gaining in popularity with electric utilities in the western United States. These companies are finding it much more economical to use a photovoltaic-powered pump than to maintain a distribution line to a remote pump on a ranch. Several utilities are offering a photovoltaic water pumping system as a customer service option. The many advantages of using water pumps powered by photovoltaic systems include low maintenance, ease of installation, reliability, and the capability to be matched to water usage needs. Most pumping systems do not use batteries but store the water in holding tanks. The photovoltaic modules are often mounted on tracking frames that maximize energy production by tracking the sun from east to west each day. The trackers use little or no power and may increase water production as much as 40 percent during summer months. The typical range of sizes for photovoltaic-powered pumps is a few hundred watts to a few kilowatts of photovoltaic array.



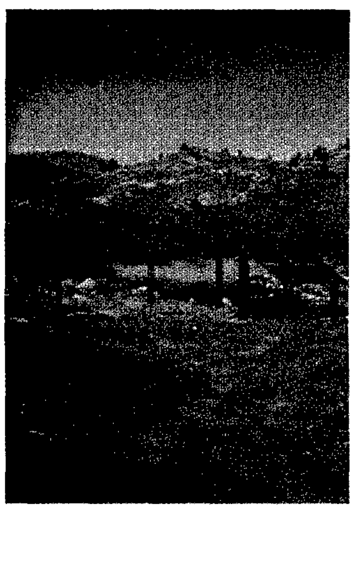
For some water pumping applications a portable power system such as the one shown is preferred. This allows the user, the National Forest Service (Austin Ranger District), to use the system at different locations during the year. At this site, the solar pump lifts water 300 feet from a stream and pumps it through a two-mile-long pipe to livestock tanks in a grazing area. This helps keep the livestock out of a sensitive riparian area.

This photovoltaic-powered water pumping system has operated reliably since 1984 at 8,000 feet elevation in the High Sierras of California. The system is one of ten photovoltaic water-pumping systems installed and operated by Inyo National Forest, headquartered in Bishop, California. The photovoltaic array is mounted atop the tower, and the well head is in the box near the base of the tower. A 10,000-gallon storage tank can be seen under its blanket of snow. This system delivers water to Big Pine Campground, about half a mile down the canyon. During summer, the system delivers about 2000 gallons of water each day.

A timer control system allows unattended operation of this photovoltaic-powered irrigation system and saves significant labor costs. These systems are used in parks and along highway medians in many western states.

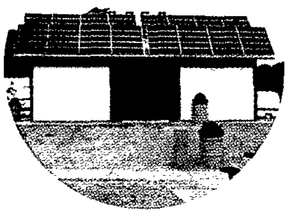


On open range in Wyoming this photovoltaic-powered water pumping system provides approximately 500 gallons of water a day for livestock. It was installed by a utility customer of the Western Area Power Administration as the most economical way to meet a rancher's need for livestock water. Like most water pumping systems the modules are mounted on trackers to get the most of each day's sunshine.



Restroom Facilities

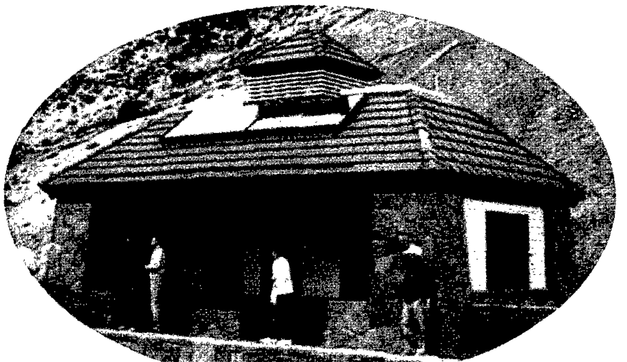
A growing use of photovoltaic systems, one ideally suited to the technology, is providing electricity for public restroom facilities in out-of- the-way locations. In many areas, recent environmental regulations require state and federal agencies to install self-contained toilet systems. These facilities are found at highway rest stops, public beach facilities, outdoor recreation parks, and public campgrounds. These comfort stations are using photovoltaic power systems to operate air circulation and ventilation fans, interior and exterior lights, and auxiliary water pumps for sinks and showers. For most of these applications, the initial cost of the photovoltaic power system is the least expensive option. This is in addition to the major benefits of improved waste treatment, sanitation, a cleaner environment, and a real plus—control of odors.



This roof-mounted photovoltaic array is located on a toilet facility at the Picacho Peak rest area along Interstate 10 in Arizona. The modules are vandal-resistant, with non-glass construction.

This photovoltaic-powered comfort station is one of several located at Coronado National Forest campgrounds in the Catalina Mountains north of Tucson, Arizona. The system was installed to provide 24-hour power for lights and ventilation fans. The pole-mounted photovoltaic array is high enough to prevent shading.

Located in the Adirondacks this photovoltaic system powers a facility offering visitors a clean, odorless, and pollution-free restroom, something thought to be impossible in such a remote location. The photovoltaic system has operated reliably since the summer of 1987 when it was installed by the State of New York Department of Environmental Conservation. The photovoltaic system cost was much less than that required to install ac utility power to the facility, and much quieter and cleaner than an engine generator.



The Gifford-Pinchot National Forest specified a photovoltaic system to provide power for lights and ventilation fans on a comfort station at the Windy Ridge Visitors Area at Mt. St. Helens National Monument, Washington. The roof-mounted photovoltaic array has a Lexan® cover over the modules to protect against possible vandalism.

Photovoltaic Systems Solve Problems

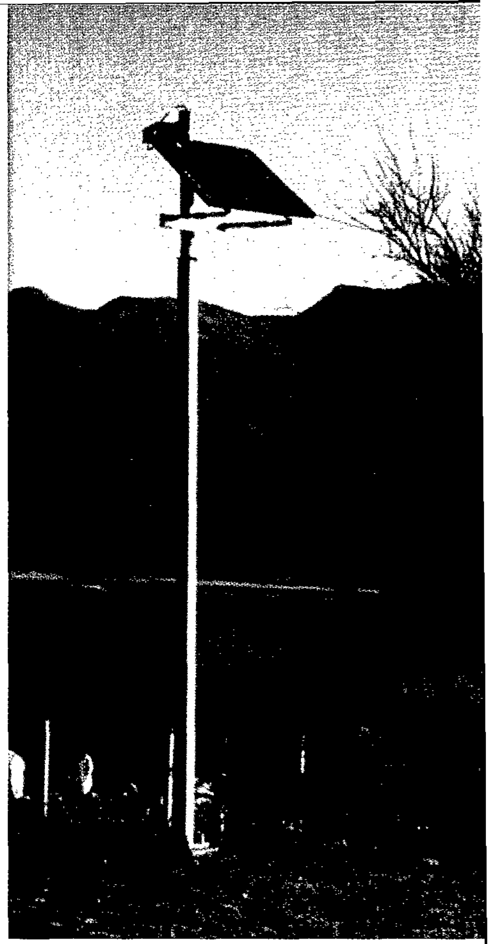
THE CHOLLA RECREATIONAL SITE

As part of the Arizona Project, the National Forest Service and the Bureau of Reclamation plan to spend $40 million developing new recreational facilities around Roosevelt Lake northeast of Phoenix, Arizona. The Cholla site, one of ten planned, is located more than 6 miles from the nearest electric power grid. Estimates for extending the grid exceeded $750,000 with monthly bills expected to exceed $1,000. Tonto National Forest personnel began to search for alternatives that would incorporate new technologies, conserve water and the natural environment, and cost less. Yet they wanted the Cholla site to have modern amenities. They contacted the PVDAC, which helped them find a photovoltaic solution.

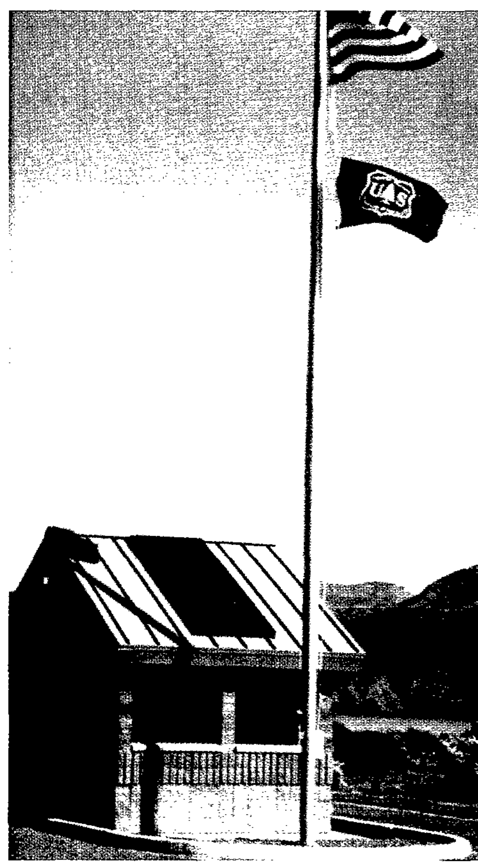
The Forest Service made a list of its initial power needs:

- Potable water from a 165' well
- Lighting and air conditioning at the entry station
- Power for a fish cleaning station
- Lighting and ventilation for 13 toilet buildings
- Area lighting for informational signs
- Security lighting at the boating site
- Power for the campground hosts' RVs

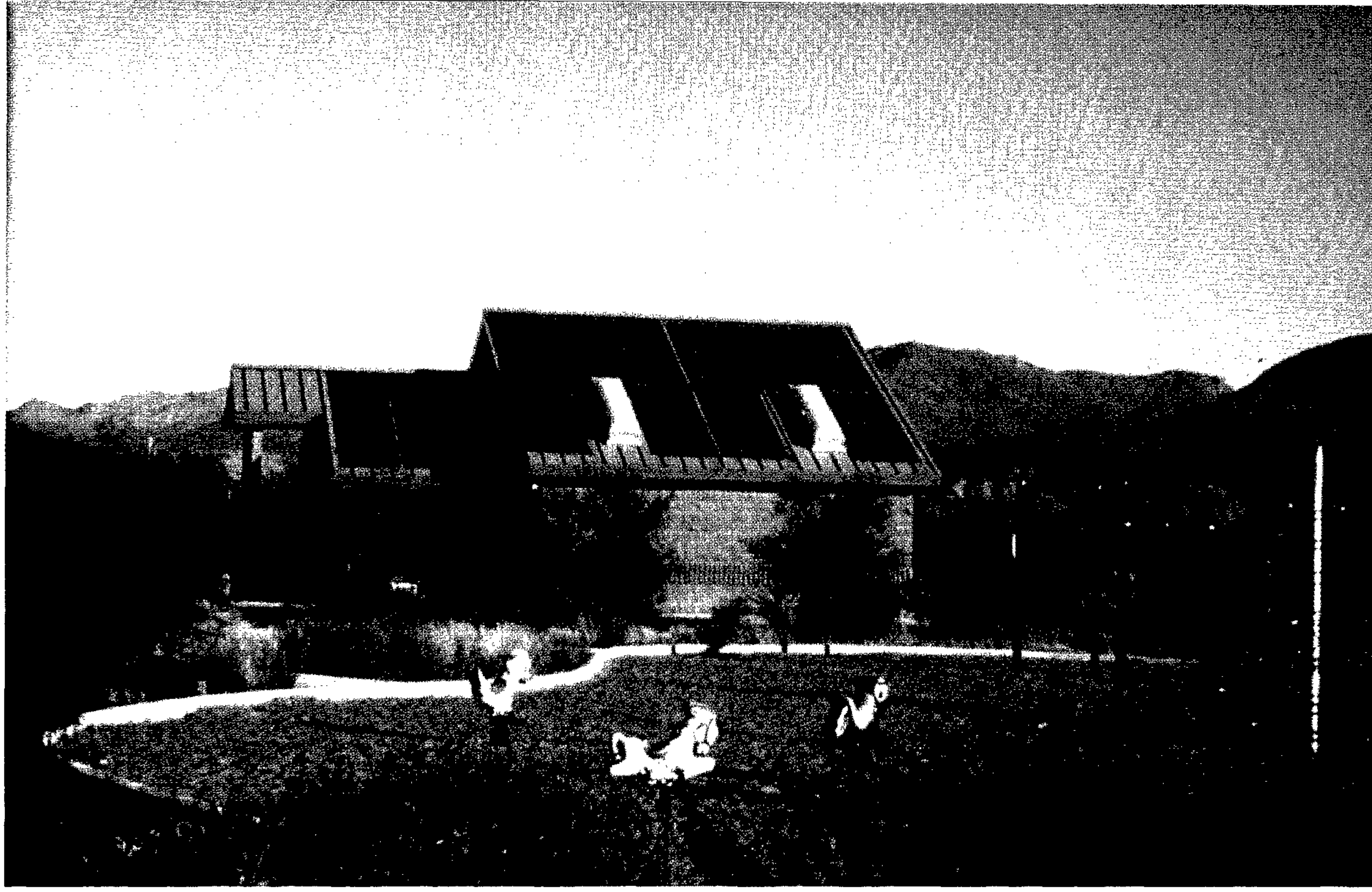
Working with the PVDAC and systems vendors, the cost estimate was $240,000. Photovoltaic systems would meet all requirements cheaper plus give the flexibility to expand or change the plans as public use of the facility dictated. The Cholla Recreational Site was opened during the summer of 1992. The site serves as a prime example of the versatility and cost-effectiveness of photovoltaic systems as well as Tonto National Forest's commitment to the use of alternative energy for remote recreational development. The Cholla Campground received a Federal Energy Award from the USDOE in 1992.



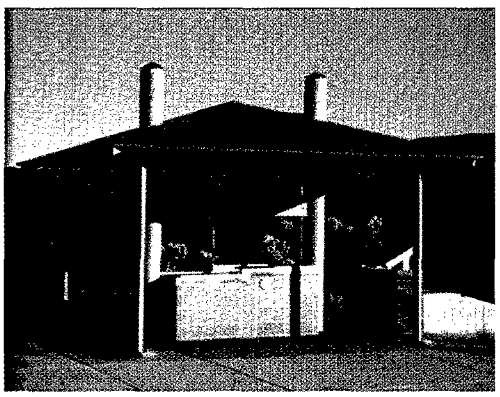
Security lighting
at boat launch area.



Lighting and air
conditioning at the entry station.



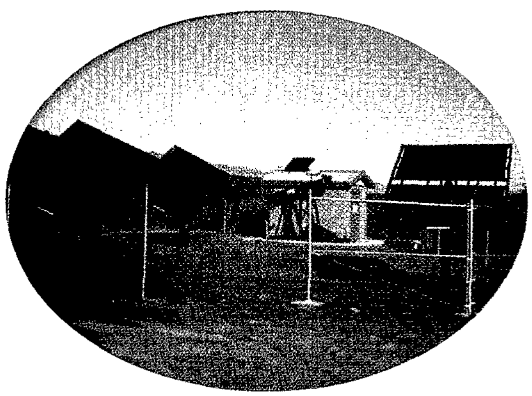
Photovoltaics provides power for lighting and ventilation for each of the three shower buildings and 10 restrooms. The shower buildings also use solar thermal collectors for hot water.



Power for a composting fish cleaning station.

Area lighting for one of several informational signs.

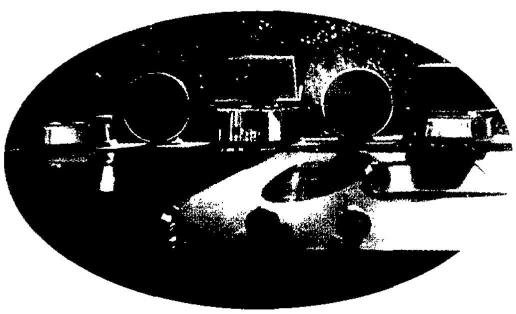
Power for one of four campground hosts' RVs.



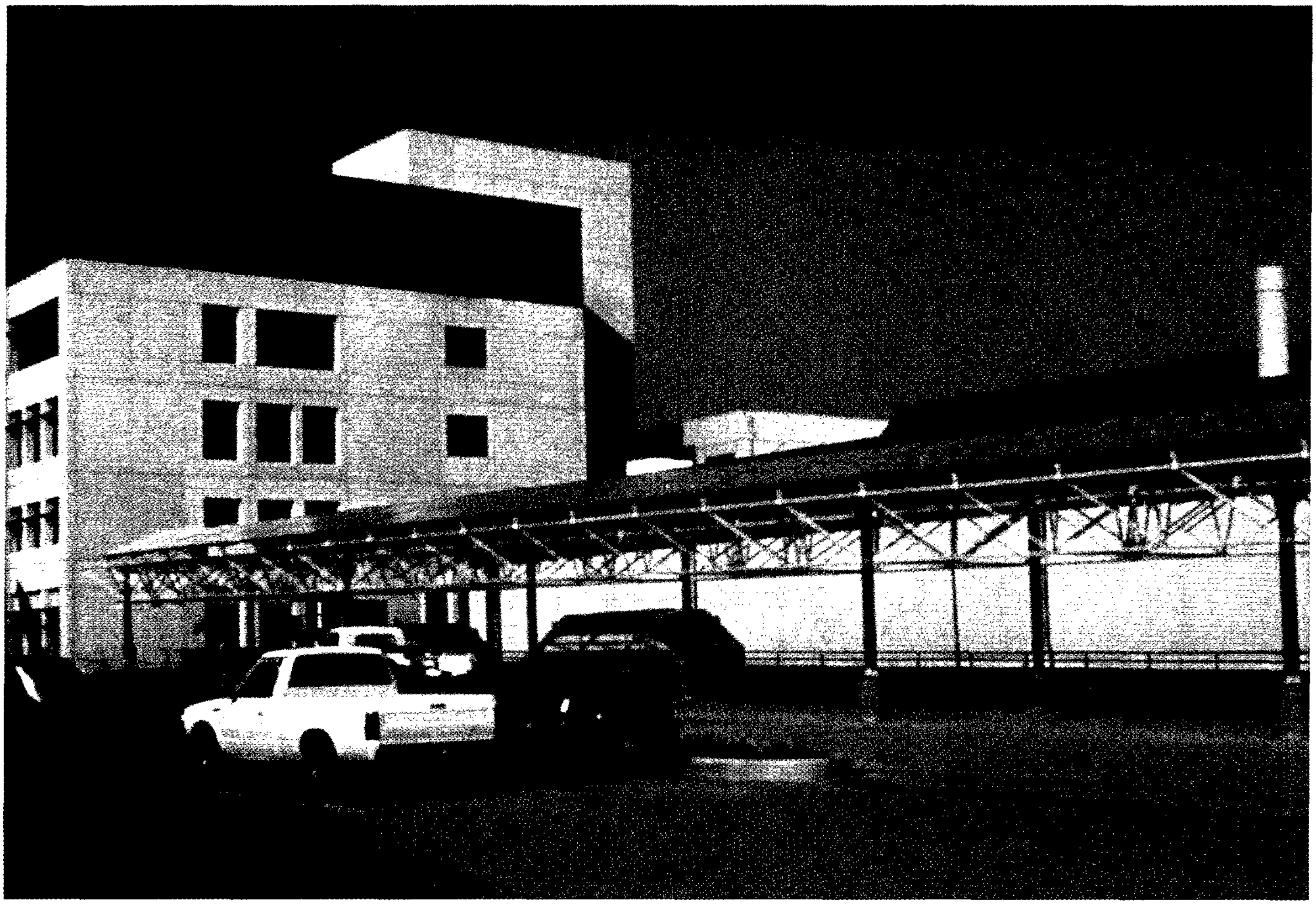
Potable water and disinfection from a 165' well.

Charging Vehicle Batteries

Vehicle batteries have an inherent problem—they self-discharge over time if they are not being used. This is a problem for organizations that maintain a fleet of vehicles, some of which are infrequently used, such as fire fighting or snow removal equipment. Photovoltaic battery chargers can solve this problem at a low cost. These small modules produce a "trickle charging current" that keeps the battery at a high state-of-charge. This increases readiness and saves thousands of dollars a year in maintenance costs for many organizations. Often the module can be placed inside the windshield and plugged into the cigarette lighter. This uses existing wiring and protection circuits and provides a quick-disconnect for the module. The photovoltaic modules are installed on the roof or engine hood of larger vehicles. Agencies using photovoltaics to maintain battery charge include U.S. military, national guard, municipal governments, and the U.S. Forest Service. A future application that is just being developed is the use of photovoltaic modules to charge the batteries in electric vehicles. The State of California has established regulations requiring 10 percent zero-emission automobiles by 1996. Electric vehicles are the prime candidate for meeting these goals. Parking an electric vehicle under a photovoltaic roof during the work day is a natural way to recharge the battery.



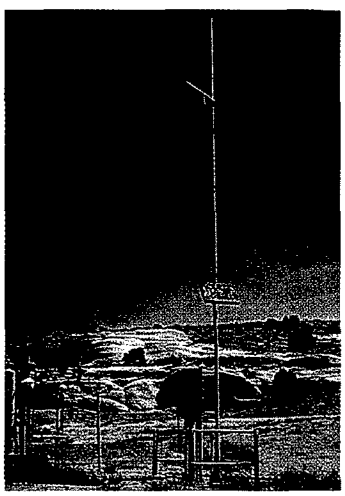
Photovoltaic modules are used to keep the batteries of this tow-truck at peak readiness. Thirty-two vehicles, including snow plows, earth graders, and service trucks are equipped with similar photovoltaic chargers by the Metropolitan District Commission in Stoneham, MA.



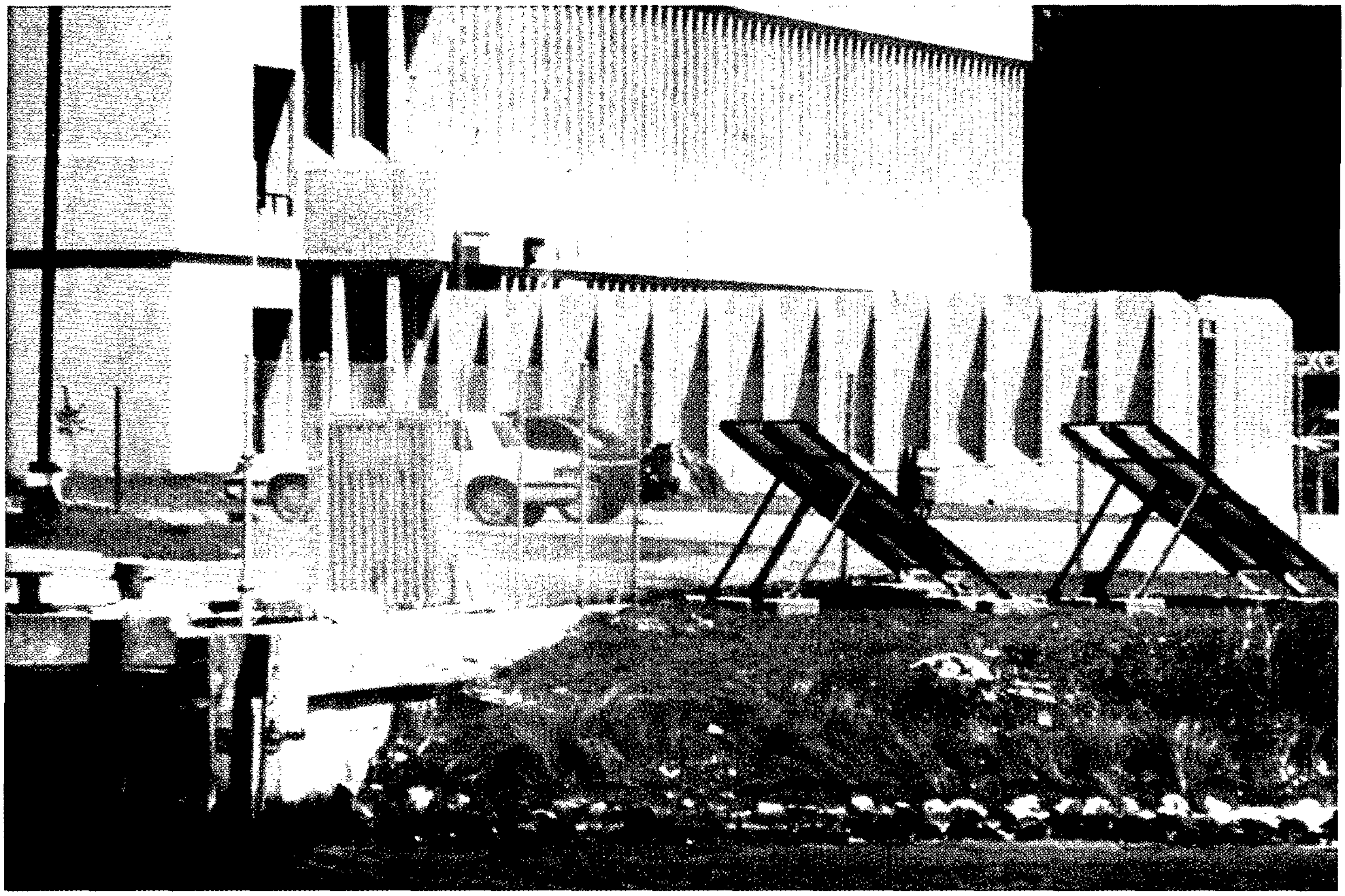
This photovoltaic roof was installed in 1992 by Southern California Edison and the South Coast Air Quality Management District. With 24 kW of photovoltaic array and 15 charging bays for electric vehicles, the facility is a prototype of what may become commonplace in the future. Excess power is used by the SCAQMD building in the background.

Cathodic Protection

Each year metal corrosion causes billions of dollars of damage to pipes, tanks, wellheads, wharves, bridges, buildings—anything made of metal and buried in earth or installed under water. Corrosion occurs because metals lose ions when they are exposed to the electrolyte (moisture and chemicals) in soils and water. Cathodic protection is achieved by applying a voltage to keep the potential difference between metal and electrolyte at a level that prevents electron loss from the metal. The amount of current depends on type of metal, composition of the soil, salinity of water, and surface area of metal to be protected. Historically, cathodic protection power was supplied by transforming ac grid power to a lower voltage, rectifying it and applying it to the cathodic protection circuit—an inefficient use of electricity. The low-voltage dc power required can be provided by batteries that are recharged daily by a photovoltaic system. The batteries keep the potential applied 24 hours per day. However, the U.S. Navy is using some cathodic protection by photovoltaic systems without batteries. These systems are active during daylight hours only. No quantitative data are available to determine the efficacy of such systems compared to those that provide power continuously, but visual observation indicates a significant slowing of corrosion. Most cathodic protection systems require less than 1 kilowatt of power. Agencies using cathodic protection include the U.S. military, highway departments, municipal governments, and the U.S. Park Service.

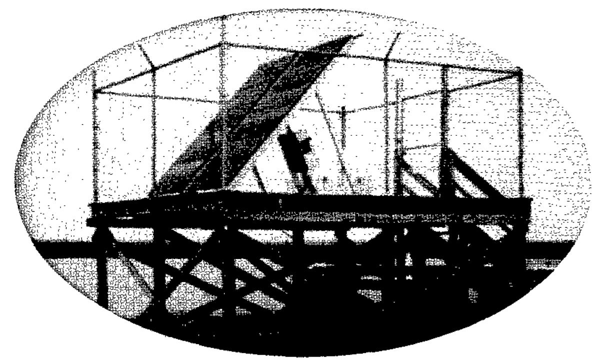


Several hundred photovoltaic-powered cathodic protection systems operate in the western states of Colorado, New Mexico, Wyoming, Utah, and Arizona. Most of these systems were installed by oil companies to protect wellhead equipment and pipelines. Many are located on state or federal lands and are meeting federal regulations for cathodic protection for buried metal structures.



The U.S. Navy is using photovoltaic power to protect 775 feet of steel sheet piling of a Navy bulkhead in Panama City, Florida. This system produces up to 90 amperes during the day. No batteries are used. This system has operated without problem since 1989. The cost of the photovoltaic system was $62,265. The estimated cost of a conventional cathodic protection system at that location was over $108,000. Because of the obvious savings and the reduction in corrosion, a similar system has recently been installed on an 800- foot bulkhead nearby.

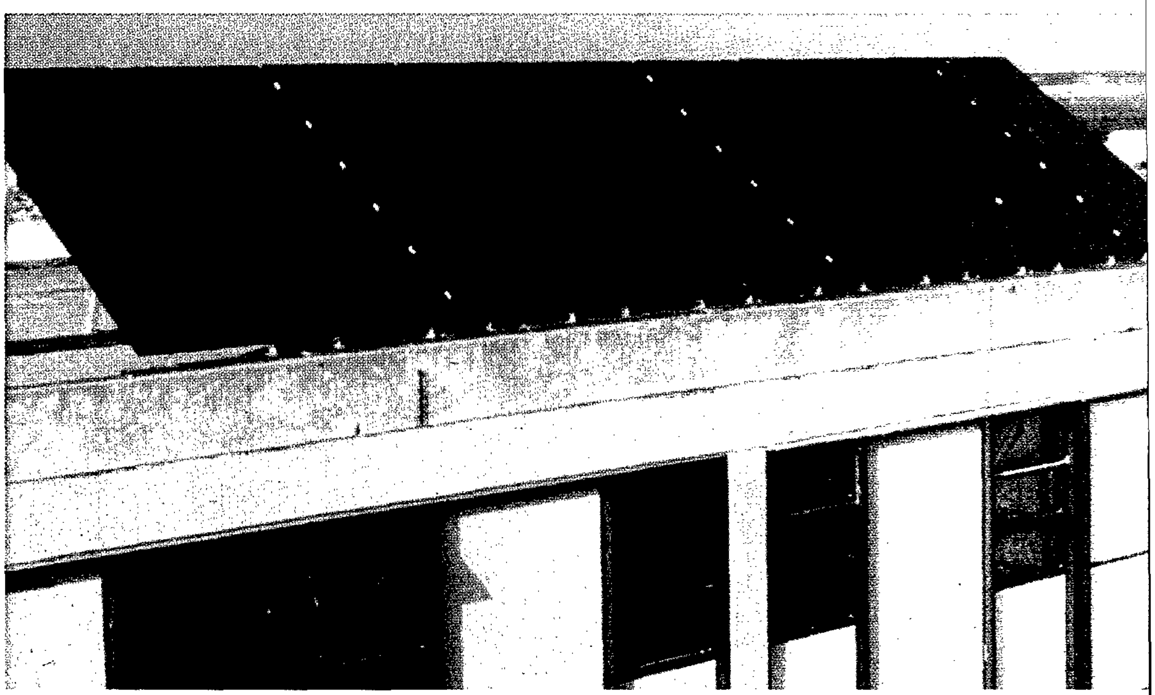
This photovoltaic-powered cathodic protection system is located in the Mississippi River delta south of New Orleans. It is typical of those used throughout the country by the oil industry and by agencies responsible for installations on government property.



Facility Power

Photovoltaics offers government agencies an attractive option to augment and/or replace engine generators for remote facility power systems. Combining photovoltaics with battery storage and engine generators into hybrid power systems provides the opportunity to maximize system efficiency and system reliability while also reducing fuel use, handling, and storage requirements. Experience has shown that facilities that rely on engine generators for electric power typically use engines which are sized for the largest electric load as well as possible future load growth. Remote power generators with less than 500kW of generation capacity usually use single generators to accommodate the loads. To ensure adequate peak power, systems must be significantly oversized. This requires the generator to operate at very low load capacity much of the time. A typical range of fuel efficiency for an engine-powered generator is between

This hybrid photovoltaic system provides facility power to an island wildlife refuge on Tern Island in French Frigate Shoals. Installed in 1987 by the U.S. Fish and Wildlife Service, the system includes 2.8 kW of array, 30 kWh of battery storage, and a 3.8 kW diesel generator. The system saves over $30,000 per year in diesel fuel and transportation costs and paid for itself in less than 2 years.



Hybrid photovoltaic systems provide power for lights, appliances, and air conditioning for three ranger residences located at Wildrose Canyon on the west side of Death Valley National Monument. These ac systems include a small engine generator for back-up power.

Photovoltaic Systems Solve Problems

THE CHANNEL ISLANDS NATIONAL PARK

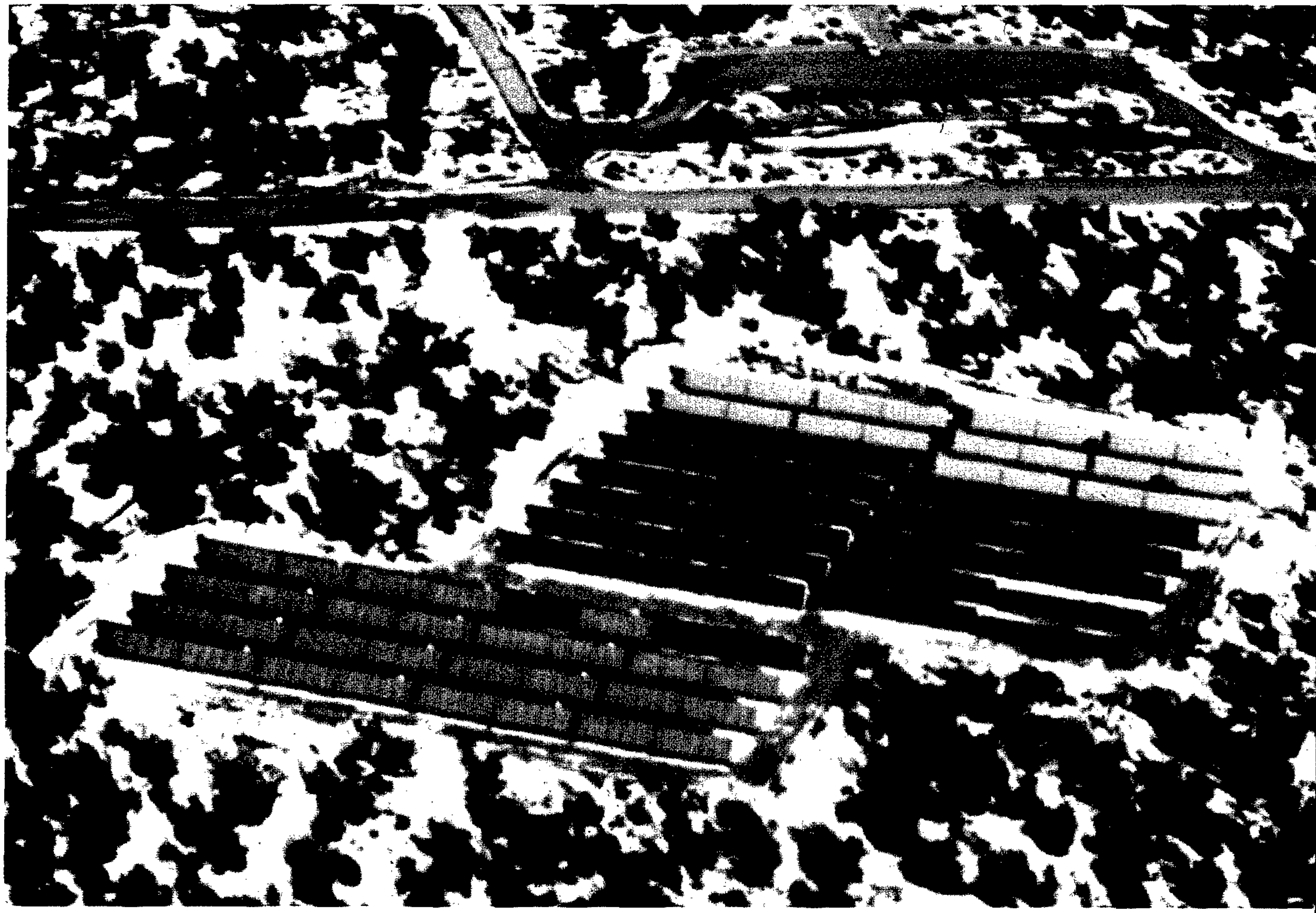
The Channel Islands National Park includes eight islands, three submerged, and their surrounding one nautical mile of ocean off the coast of Southern California. The islands and the kelp forests are home to varied aquatic wildlife and birds, some of which are listed as endangered species. The National Park Service is using photovoltaic systems to provide power compatible with the environment and the responsible recreational development of these remote facilities. Photovoltaic power has been used for the lighthouse on East Anacapa Island since 1981. The power system was recently upgraded and now provides power for the light and a high-intensity foghorn. As development continues, photovoltaic power will be used for the remote facilities, water pumping, and communications. Photovoltaic-powered ranger stations are maintained on Anacapa and Santa Barbara Islands. Park plans call for new photovoltaic-powered facilities on Santa Rosa Island.

Photovoltaic power is being used for residential loads like the ranger residence and visitor center on Santa Barbara Island in the Channel Islands National Park. The National Park Service is installing many photovoltaic systems in line with its Sustainable Design Initiative.

6 kWh per gallon of fuel at 10 percent load and 13 kWh per gallon at 90 percent load. In addition, maintenance on engine generators is based on engine run time and not on energy output. Using batteries and photovoltaics with engine generators allows the engine to operate at full load capacity (and maximum fuel efficiency) during its run time by storing excess generation in batteries. Photovoltaics charge the batteries during daylight hours to minimize engine run time thus saving fuel and maintenance costs while also providing significant environmental benefits in reduced exhaust emissions. This means the engine can be turned off for extended periods, especially at night when loads are at a minimum. Overall, the engine run time is reduced—possibly eliminated except for emergency use—and the facility meets its power need with reduced noise, exhaust, and operating costs. One other benefit should also be noted for agencies operating facilities in sensitive environmental areas. The risks of transporting, handling and storing diesel fuels can be significantly reduced by hybrid photovoltaic systems. Again, experience has shown that the clean-up cost of one fuel spill, whether on land or water, usually exceeds the total cost of converting an engine-powered generator to an all-photovoltaic facility power system.

The Cal Black Memorial Airport

located near the Glen Canyon National Recreation area is the first solar powered airport in the U.S. The hybrid photovoltaic/engine power system was installed by San Juan Co., Utah, and provides power for the airport's rotating beacon, tarmac lights, building lights, a well pump, and the airport's automatic control system.



This hybrid photovoltaic system, the largest stand-alone PV system in the U.S., was installed by the National Park Service and the U.S. Department of Energy in 1980 to provide facility power to Natural Bridges National Monument. This system provided reliable operation meeting the electrical loads of a visitors center and rangers' residences until 1989 when the useful life of the batteries expired. The system was mothballed and a 30-kW diesel generator was used until 1992, when the system was restored with new batteries and returned to service. The system saves $25,000 a year in diesel fuel and maintenance costs and because it is a noiseless, pollution-free source of power, it is compatible with sustainable operation of the park.

SHOULD YOU BE USING A PHOTOVOLTAIC SYSTEM?

You should consider using photovoltaic power for your application if it will increase your agency's ability to perform its mission or save you money. Compare the total costs—installation, operation and maintenance—of the various power options. Engine generators always cost less initially than an equivalent amount of photovoltaic power, but expensive operation and maintenance costs combined with environmental concerns escalate the cost of energy to more than $0.30 per kWh. Electricity from an existing utility grid costs three to five times less per kWh than energy from a photovoltaic system. However, getting the utility lines to your site may cost more than $30,000 per mile. As illustrated by the systems in this booklet, there are many applications for which photovoltaic power will save you money over the lifetime of the system. Consider the following factors:

- Access to the site: A well-designed photovoltaic system will operate unattended. The savings in labor costs and travel expenses can be significant.
- Fuel Supply: For some sites, the logistics of transporting fuel to the site and then storing it in an environmentally safe manner can be much more expensive than the fuel itself.
- Maintenance: Any energy system requires maintenance. Experience shows that maintaining a photovoltaic system is less expensive than most alternatives.
- Durability: Photovoltaic modules have no moving parts, and degradation is minimal. Some photovoltaic modules have been operating in harsh environments for 15 years with no measurable decrease in output power.
- Modularity: A photovoltaic system can be designed for easy expansion. If the power demand might change in future years, the ease and cost of altering the power supply should be considered.
- Environmental impact: Installation and operation of a photovoltaic system has little effect on the environment—an advantage that cannot be claimed by most other power sources.
- Security-related issues: Attributes of photovoltaic systems are quiet operation, no emissions or fuel dependence.
- Evaluate your application. If some of the points above apply, the chances are good that photovoltaic systems are being used in similar applications.

WHAT NOW?

How do you buy a photovoltaic system? If you are with a federal agency, you may buy from the GSA price list. Contact a photovoltaic systems dealer. Some of the products shown here exist as packaged systems that can be ordered from a dealer. A box will arrive with all necessary parts and installation instructions. If you need or want a customized system, most photovoltaic dealers will work with you to engineer the best system for your application. They will help you determine your requirements by

- Estimating the daily load demand
- Determining the solar resource in your area
- Calculating the battery size
- Calculating the number of photovoltaic modules required.

These estimates can be made with simple worksheets like those found in ***Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices.*** This Sandia publication, available from the PVDAC, gives details on the sizing of 16 complete photovoltaic systems for various applications. If you need assistance, the PVDAC can provide information and design expertise. The staff will help you define your needs and provide contacts within the photovoltaic industry that can meet your requirements. The PVDAC provides training and workshops on system design, economics, operation, safety, and maintenance. The PVDAC is funded through the National Photovoltaics Program by the U.S. Department of Energy.

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PREFACE

This report was written to encourage government agencies to use photovoltaic power systems for all cost-effective applications. There are dozens of them. We included the most popular applications in this booklet. We chose from hundreds of photographs representing thousands of systems. The use of photovoltaic systems to meet the needs of remote power applications, such as lights, water pumps, and residences, continues to increase more than 15% a year. We know they are becoming commonplace. Specifying and buying photovoltaic hardware is becoming easier as the number of installations and users increases. You can buy complete systems from dealers—there are probably solar system suppliers listed in your yellow pages—or you can buy components and build the systems yourself. With careful installation, you will get a reliable long-term solution to your power supply needs. If you need help or the latest information about photovoltaic options, the Photovoltaic Design Assistance Center (PVDAC) is ready to assist you.

These documents are available from the PVDAC.

Risser, V., and H. Post, Editors. ***Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices.*** SAND87-7023, Sandia National Laboratories, Albuquerque, New Mexico, November 1991.

Risser, V., ***Working Safely With Photovoltaic Systems.*** Photovoltaic Design Assistance Center, July 1991.

Holz, M., ***Maintenance and Operation of Stand-Alone Photovoltaic Systems.*** Naval Facilities Engineering Command, Southern Division; DoD Photovoltaic Review Committee; Photovoltaic Design Assistance Center; December 1991.

Wiles, J., ***Photovoltaic Systems and the National Electric Code—Suggested Practices.*** Photovoltaic Design Assistance Center, November 1992.

Risser, V., ***Hybrid Power Systems—Issues and Answers.*** Photovoltaic Design Assistance Center, July 1992.

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